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COMPARISON OF SPATIAL SUMMATION AND THRESHOLD VERSUS RETINAL ECCENTRICITY FUNCTIONS IN NORMAL AND DEUTERANOPIC OBSERVERS

by

George A. Geri and David F. Neri

Naval Medical Research and Development Command
Research Work Unit MR000.01.01-5079

Released by:

R. A. Margulies, Capt, MC, USN
Commanding Officer
Naval Submarine Medical Research Laboratory

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I

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II

SUMMARY PAGE

PROBLEM

To investigate the theoretical prediction of a difference between normal and color-defective individuals in visual sensitivity to red test lights.

FINDINGS

There was no evidence that normals differed from color defectives in either their sensitivity to changes in the area of a foveally presented red stimulus or their sensitivity to a red stimulus presented peripherally.

APPLICATION

This is basic research designed to assess differences in visual function between normal and color-defective individuals. Such assessment is important for the selection and classification of color defectives for the Navy.

ADMINISTRATIVE INFORMATION

This investigation was conducted under Naval Submarine Medical Research Laboratory Work Unit MR000.01.01-5079 - "Directional sensitivity in cone mechanisms of color defective individuals." It was submitted for review on 6 June 1980, approved for publication on 12 Jun 1980 and designated as NAVSUBMEDRSCHLAB Report No.935.

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ABSTRACT

Spatial summation functions were determined for three deuteranopes and three age-matched normal trichromats under stimulus conditions which favored stimulation of the long-wavelength receptor system. No differences were found in the data of the two groups suggesting that some modification of existing threshold models is necessary.

INTRODUCTION

There are a number of theories[1] as to the nature of the anomaly by which normal trichromatic vision is reduced to the dichromatic condition of deuteranopia. All theories would seem to predict, however, that deuteranopes have at least as many long-wavelength receptors as trichromats and hence should be at least as sensitive to red light. Verriest and Uvijls[2] have found that under certain stimulus conditions deuteranopes are less sensitive to red light than are normal trichromats. This finding has been confirmed by King-Smith and Dain[3] who used a threshold model[4] based on differences in post-receptoral processes to explain it. The model postulates that the red-center, green-surround opponent-process organization of normal trichromats is in deuteranopia altered to a red-center, red-surround organization. This model is consistent with threshold data obtained from deuteranopes[1,2] and would predict differences in spatial summation between deuteranopes and normals. The present study tests that prediction by comparing the spatial summation functions of normals and deuteranopes. Threshold versus retinal eccentricity functions were also obtained for both groups of observers.

METHOD

Observers. The observers were three deuteranopes and three age-matched trichromats. All observers were screened using the AO HRR Pseudo-Isochromatic Plates and the Nagel Anomaloscope. A MacAdam binocular colorimeter was then used to establish that the three suspected deuteranopes could make a two-primary (P_1 = 642 nm, P_2 = 435 nm) match to 2° test stimuli ranging in wavelength from 444 nm to 567 nm.

Apparatus. A Tubinger perimeter was used for all increment threshold measurements. A circular test stimulus, whose area could be varied, was presented either in the fovea or in the nasal field of the right eye. Stimulus duration was 0.1 sec. The spectral distribution of the test stimulus was determined by a Schott RG2 red, cut-off filter (50% transmittance at 635 nm). The unattenuated test stimulus had a luminance of 9.18 fL. The spectral distribution of the adapting field was determined by a Wratten No. 45 (blue-green) filter, and its luminance was 0.03 fL. For all parafoveal threshold determinations, a barely visible 10' red fixation light was used. For foveal threshold determinations, the observer was instructed to fixate the center of a diamond-shaped array (1.5° on a side) of four 10' dim red lights.

Procedure. With the left eye occluded, observers adapted to the background for about eight minutes. A staircase procedure was used and thresholds were determined by averaging the midpoints of six to ten response reversals. Log threshold versus retinal eccentricity functions were obtained using a 10' diameter test stimulus presented at the fovea and out to 30° in the nasal field in 5° increments. Spatial summation functions were obtained at the fovea with seven stimuli varying in diameter from 7' to 110' and producing stimulus areas of 1.59, 1.90, 2.36, 2.73, 3.14, 3.53, 3.98 log min^2. For each observer an experimental session consisted of a threshold determination for either the seven retinal positions or the seven stimulus areas presented in a random order.

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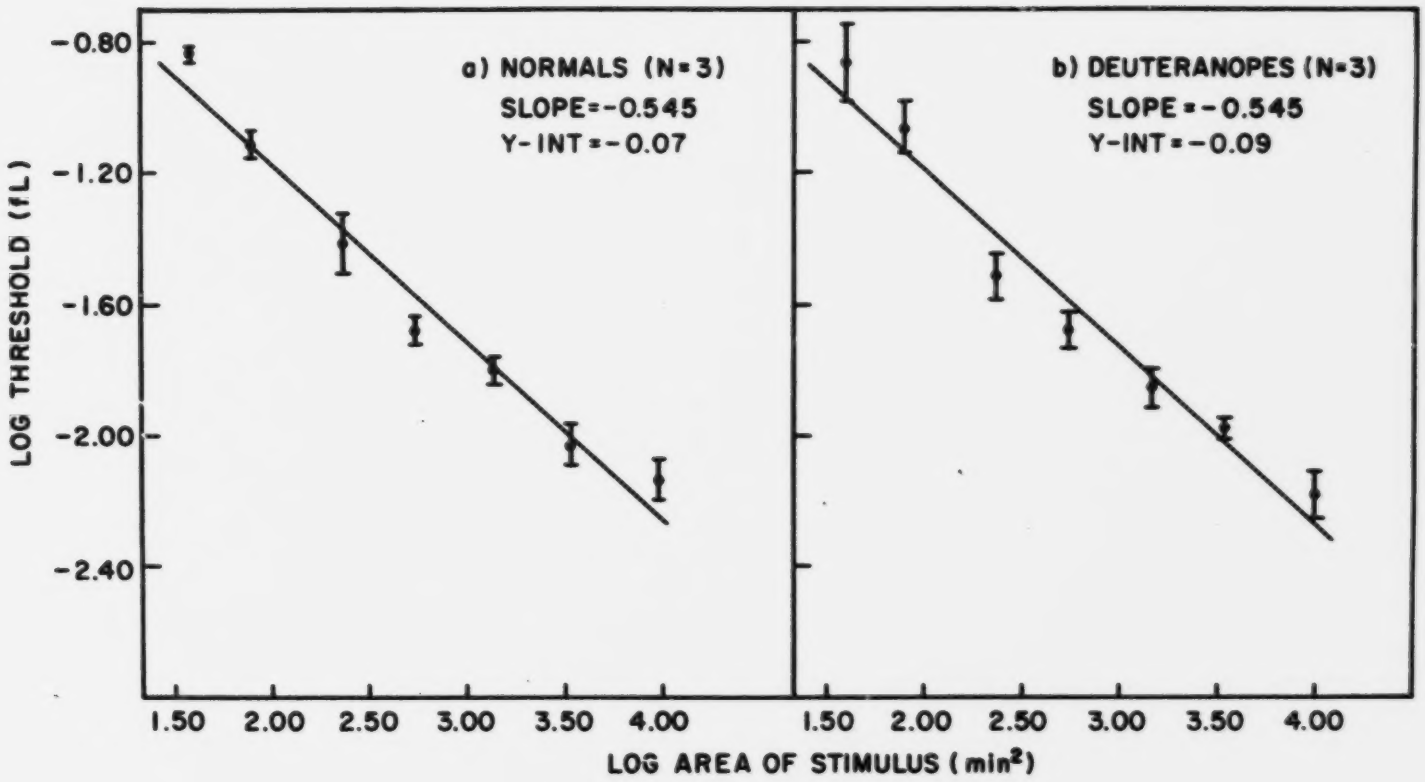

Fig. 1. Spatial summation data from three normal (a), and three deuteranopic (b) observers, obtained using a foveal, red, 100 msec test stimulus presented on a dim blue-green adapting field. The linear functions represent the best least-squares fit to the data. The error bars represent ± 1 s.e.m.

Statistical Analysis. Linear functions were fitted to both the individual and mean log threshold versus retinal eccentricity and log threshold versus log stimulus area data using a least squares criterion. A test for trend[5] was performed on both sets of data for both deuteranopes and normals. T-tests[6] were performed on the slopes and log threshold intercepts of the functions fitted to the individual data in order to determine if the deuteranopes' data differed significantly from those of the normal observers.

RESULTS AND DISCUSSION

Figure 1 shows the decrease in mean threshold for both the deuteranopic and normal observers as the area of the test stimulus was increased. The best fit linear functions and their slopes and ordinate-intercepts are shown in the figure. The null hypothesis of no linear trend in the data was rejected ($p<10^{-9}$) while the hypothesis of no curvilinear trend was not ($p > 0.17$, deuteranopes; $p > 0.07$, normals). It is concluded that the relationship between test stimulus luminance at threshold and stimulus area is well approximated by a power function. There were no significant differences ($p>0.7$) in the slopes or ordinate-intercepts of the deuteranopic and normal functions indicating no differences in sensitivity and no differences in spatial summation over the range of test stimulus areas presented.

Verriest and Uvijls[2] found that under certain stimulus conditions, deuteranopes are less sensitive than normals to red test stimuli. A threshold model[3,4] has been put forth which attempts to explain the lowered sensitivity of deuteranopes as due to a change in the functional organization of their opponent-color system. Rather than the normal red-center, green-surround organization, it was suggested that the deuteranopes' system might have a red-center, red-surround organization. A red test stimulus would therefore stimulate the inhibitory component (red-surround) of the deuteranopic system but not the inhibitory component (green-surround) of the normal system resulting in reduced sensitivity for the deuteranopes. Although this model is consistent with the data of Verriest and Uvijls[2], a logical extension of it would lead to the prediction of differences in spatial summation between deuteranopes and normals. As the area of a red test stimulus is increased, it will at some point stimulate the inhibitory surround of the deuteranopes' receptive fields resulting in reduced sensitivity relative to the normal observer. All test stimuli used to obtain the spatial summation functions of Figure 1 appeared colored to all observers. If the assumption[7] that the appearance of color implies detection by the opponent-color system is valid, then the fact that the deuteranopes of the present study did not show a lowered sensitivity, relative to the normal trichromats, as test stimulus area was increased, is inconsistent with the model proposed by King-Smith and Dain[3] and King-Smith.[4]

The data of Figure 2 show the decrease in mean sensitivity for both the deuteranopic and normal observers as the stimulus was moved from the fovea to 30° into the nasal field of the observers' right eyes. The best fit linear functions and their slopes and ordinate-intercepts are also shown in the figure. The null hypothesis of no linear trend in the data was rejected ($p<10^{-5}$) while the hypothesis of no curvilinear trend was not ($p > 0.60$). It is concluded that the data of Figure 2 represent an

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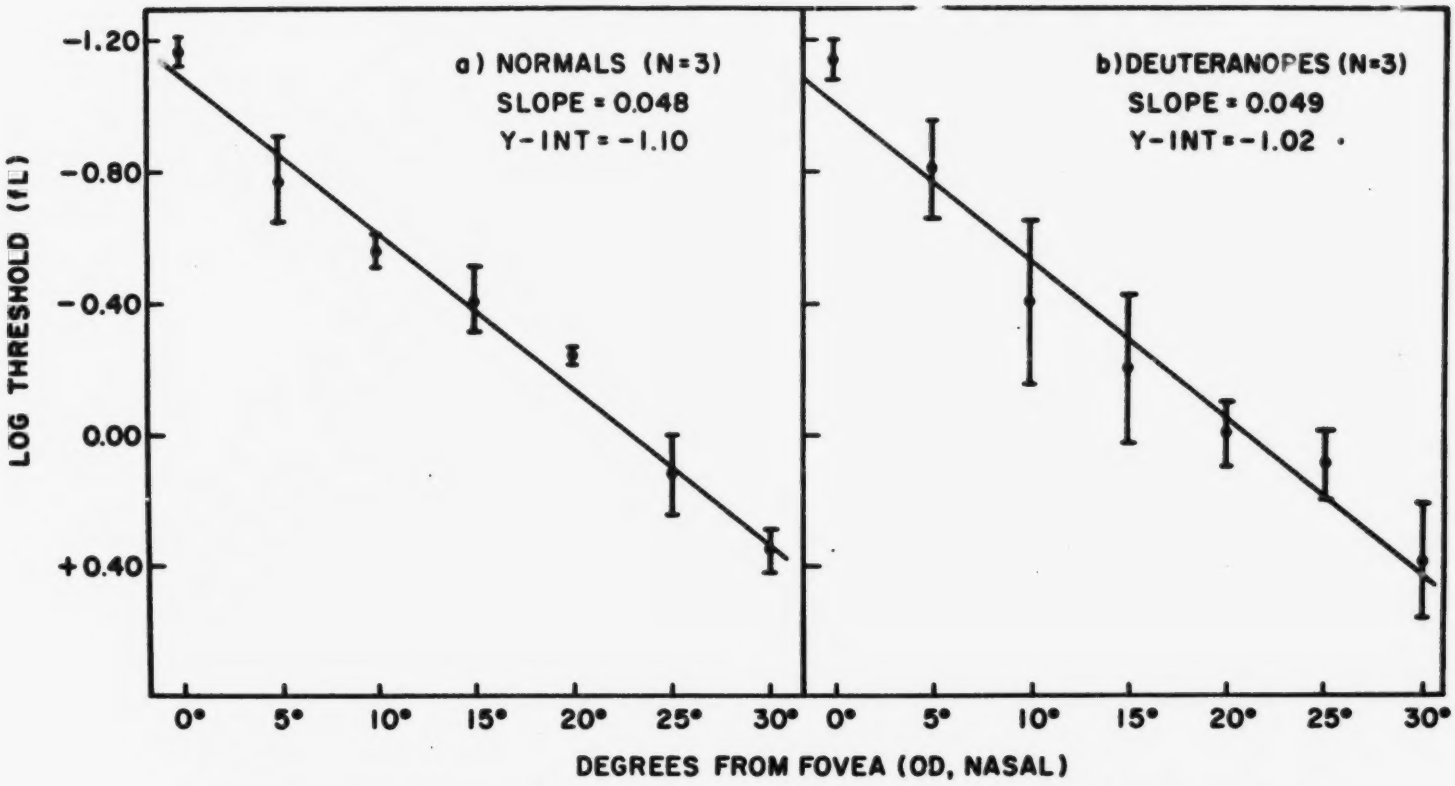

Fig. 2. Log threshold versus retinal eccentricity data from three normal (a), and three deuteranopic (b) observers, obtained using a red, 10', 100 msec test stimulus presented on a dim blue-green adapting field. The linear functions represent the best least-squares fit to the data. The error bars represent ± 1 s.e.m.

approximately exponential decrease in sensitivity with distance from the fovea.

There were no significant differences ($p > 0.50$) in the slopes or ordinate-intercepts of the deuteranopic and normal functions again indicating no differences in the sensitivity of the two groups. Verriest and Uvijls[2] carried out a similar experiment with a larger group of observers and concluded that there were significant differences in sensitivity between deuteranopes and normals. King-Smith and Carden[7] have put forth a threshold model which may be relevant to a comparison of the present data with those of Verriest and Uvijls.[2] The model proposes that threshold may be determined by either an opponent-color system or a luminance system depending on the test and adapting stimulus parameters chosen. Large, long duration test stimuli and intense white adapting fields, for instance, would tend to favor the opponent-color system over the luminance system. Verriest and Uvijls used a 1°, 500 msec test stimulus and a 10 cd/m^2 adapting field, whereas a 10', 100 msec stimulus and a background of 0.1 cd/m^2 (0.03 fL) were used in the present study. The King-Smith and Carden model suggests that we stimulated the luminance system and Verriest and Uvijls stimulated the opponent-color system. Thus, they may have found a difference in the functional organization of the opponent-color systems of the two groups while we found no difference because the luminance system is the same for both groups.

There is, however, one aspect of the data of Figure 2 which argues against this explanation. As noted above, King-Smith and Carden associate the appearance of color at threshold with detection by the opponent-color system. All the observers in the present study always saw the test stimulus at 0° and 5° as colored, which argues against the notion that detection was mediated by the luminance system. Thus, if according to the criterion of King-Smith and Carden, the opponent-color system determined threshold in both the present study and that of Verriest and Uvijls,[2] then the King-Smith and Carden model does not explain both sets of data.

It is clear that the major difficulty here is how to specify the stimulus conditions under which the opponent-color or the luminance system determines threshold.[8] The present data would not be inconsistent with the King-Smith model if the colored appearance of the test stimulus were not taken to indicate detection by the opponent-color system.

Because no differences were found between deuteranopes and normals, the present data can be explained by assuming either a simple loss of the middle-wavelength receptor system or a fusion of the long- and middle-wavelength systems in deuteranopes.[1] However, differences have been found between deuteranopes and normals under certain stimulus conditions[2,3] and these can most easily be explained by postulating differences in the post-receptoral organization of the deuteranopic and normal visual systems.[3,4] Although the present data are not consistent with the specific post-receptoral model put forth by King-Smith[4] and King-Smith and Dain,[3] they suggest only that some modification of that model is necessary. The nature of the

necessary modifications will depend, at least in part, on whether stimulus conditions can be found under which the spatial summation properties of deuteranopes and normals are different. Some possible modifications include pigment shifts in one or more[9] of the receptor systems with input into the opponent-process stage, interactions of the short- and long-wavelength receptor systems at an opponent-process stage, and the complete absence of opponent-process organization in deuteranopes.[3]

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